GENERATING ACCOUNTABILITY INDICATORS FOR AIR QUALITY:
A FRAMEWORK FOR ECOSYSTEM AND HUMAN HEALTH ACCOUNTABILITY

I. Abstract Summary Information (1 page)

Project Leads and Key Collaborators: Valerie Garcia, Deputy Director, Atmospheric Modeling Division, ORD/NERL and Dr. Halûk Özkaynak, Senior Scientist for Exposure, ORD. Key Collaborators include Dr. Nancy Kim, NY State Department of Health, Dr. Pat Kinney, Columbia University, Rick Artz, Acting Director, Air Resources Lab, NOAA, John Langstaff, OAR/OAQPS, Deborah Burgin, OEI/OIAA, and Tom Scheitlin, OEI/OTOP

Project Period: January 2007 – December 2008

Project Summary:
Previous research has shown that high ozone levels impact the health of humans and ecosystems. The formation and distribution of ozone is driven by chemical interactions involving nitrogen oxides (NOx) and Volatile Organic Compounds (VOCs) in the presence of sunlight, as well as interactions with meteorology. The role of NOx in the formation of ozone is particularly important because ozone produced from NOx emissions in one state can be transported to states downwind, contributing to pollutant levels at locations much farther from the emission source. To address this problem, EPA implemented the NOx SIP Call in 1998, requiring reductions in summertime NOx emissions by May 1, 2004 in 21 eastern states (reductions actually began in 2003). This recent regulatory action, coupled with the established relationship between high ozone levels and human health endpoints, provides a unique opportunity to establish indicators of accountability and human exposure for the Report on the Environment (Topic Area III). This effort will also enhance existing infrastructure to generate indicators through the GEOSS Remote Sensing Information Gateway (Topic Area V). This effort leverages the optimized Bayesian fusion technique refined under the FY 2006 "Modeling Fused Spatial Data" AMI Pilot, and methods to link air quality to human exposure under the FY 2006 "Implementing the PHASE Toolkit" AMI Pilot, and provides an accountability framework to examine the impacts of Clean Air Interstate Rule (CAIR), the Clean Air Mercury Rule (CAMR), and other future rules.

Deliverables: This highly leveraged effort will generate indicator maps for the Eastern United States that will quantify and track: (1) the impact of the NOx SIP Call on ozone transport across state boundaries, and (2) the probability of ozone exposure to populations living in the Eastern United States. The first indicators for these two areas will be generated using retrospective data from before and after the implementation of the NOx SIP Call. The capability to produce indicator maps on a daily-to-annual basis using daily air quality forecasts will then be demonstrated. In addition, this effort will assesses the value of the indicator maps by using them in a risk assessment and health assessment.

Performance Measure: Substantially move the organization towards generating indicators on a routine basis to track progress on regulatory actions and estimate human exposure by delivering at least 2 indicators that achieve this for the assessment of the NOx SIP Call and other emission reductions.

II. Project Implementation Plan (4 pages)

Approach: This effort will leverage ongoing work within EPA, NOAA, New York State and academia to examine the effectiveness of the NOx SIP Call in reducing ozone transport, and develop the methodology and data archive necessary to track the benefits of regulatory actions in the future. In general, we compare pre-NOx SIP Call ozone levels (1997-1998, 2001-2002) to post-NOx SIP Call levels (2004-2005) using combined observational and modeling approaches, time-series analysis and other analytical techniques. The effect of emissions and meteorology are evaluated to understand what drives the formation of ozone and its transport. These maps of ambient ozone concentration will then be used to derive population-based exposure models. The impact of several factors ranging from human activities to weather conditions that influence ambient, indoor and personal ozone concentrations will be evaluated to produce isopleth maps depicting the probability of a population being exposed to ozone above given threshold levels. These ozone concentration and exposure probability estimates will be provided to Columbia University for a risk assessment, and the New York State Department of Health (NYSDOH) for evaluation with health endpoints (e.g., respiratory-related hospital admissions). Methodologies established by the NYSDOH under the CDC-funded Environmental Public Health Tracking System will be applied in this study and represents a substantial collaboration associated with this effort.

In collaboration with the EPA/OEI and NOAA, the capability to use daily air quality forecasts in this process to produce ambient ozone concentration and exposure estimate indicator maps on a daily-to-annual basis will be developed and housed at the Remote Sensing Information Gateway (RSIG). A GIS tool will be developed to ease the use of, and enhance the access to, data through the RSIG. The methodologies developed through this pilot project are transferable to quantify and track the impacts of other regulations (e.g., CAIR and CAMR) as part of the accountability program.

The science questions that will be addressed by this pilot are: Did the NOx SIP Call result in decreased ozone levels transported across state boundaries? What is the magnitude of meteorological impacts on ambient ozone concentration levels? What is the overall impact of the NOx SIP Call on ambient ozone concentrations? How much do anthropogenic vs. biogenic emissions contribute to overall ambient ozone concentrations? Did the NOx SIP call result in a detectable decrease in exposures to populations? What drives exposure [e.g., activity patterns, weather, emissions]? Do the fused ambient ozone concentration maps improve exposure estimates? Do the exposure estimates improve the risk or health assessments? What is the effect of various emission scenarios on residual risk? Can we characterize and track the magnitude of changes in hospital admissions for respiratory diseases? Can we discern a signal in the NYS health data associated with the NOx SIP Call? Can we automate the development of indicator maps using daily air quality forecasts?

The scientific approach for addressing these questions is discussed below by major task area: Air Quality Characterization, Ozone Exposure Probability Estimates, Risk Assessment and Health Assessment. The Delivery System is discussed in Section III. The project resources, schedule and near-term and long-term benefits are provided in Section IV.

Air Quality Characterization: We have made much progress with current research in characterizing ambient ozone concentrations for the Eastern United States through comparisons of pre- and post-NOx SIP Call observations and modeled outputs. The ozone ambient concentrations measured by the CASNET and Air Quality System (AQS) networks were used for the comparison of observations between pre- (1997-1998) and post- (2003-2004) NOx SIP Call time periods for the summer ozone season (June 1 – August

31). The Community Multiscale Air Quality (CMAQ) model (Byun and Schere, 2006), run at 12km horizontal grid spacing, was used to produce the pre- (2001-2002) and post- (2004-2005) NOx SIP Call modeled output during the summer ozone season (June 1 – August 31). The Continuous Emissions Inventory was used to assess NOx emissions for both observations and for modeled simulations.

Because the production of ozone is directly related to weather conditions (dry, hot days produce more ozone than cool, wet days), meteorology was taken into account when evaluating changes between the pre- and post-NOx SIP Call periods for both observations and the modeled simulations. Ozone observations were meteorologically-adjusted by filtering the synoptic and seasonal signals (short-term variations induced by meteorology and seasonality) using the KZ Filter technique (Rao and Zurbenko, 1994; Rao, et al., 1997) and other statistical methods. Meteorology and emissions were held constant for the model simulations to extract the meteorological versus emission signals in the modeled ozone concentrations. In both cases (observed and modeled), a strong signal was detected between the pre- and post-NOx SIP Call periods due to the reduction in NOx emissions (Gego, et al., 2996 In review; Godowitch, et al., 2006).

Current research using the CMAQ model is now investigating the impact of *not* implementing the NOx SIP Call by removing the reductions to electrical generating units specified by the NOx SIP Call, and applying an energy growth factor to the emissions inventory used in the model. A simulation removing all anthropogenic emissions from the inventory will also be run. These last two scenarios will provide upper- (no NOx controls = maximum emission levels) and lower- (no human-induced emissions = minimum emission levels) bound limits to investigate the best- and worst-case scenarios for the production of ozone, and to evaluate the most significant drivers behind changes in ozone ambient concentrations, exposure factors, and health endpoints.

To further enrich the data, we will use the optimized Bayesian fusion technique and other innovative approaches to combine ground-based observations with the CMAQ simulations described above (leverages AMI PHASE effort). Using these enriched maps, three isopleth indicator maps will be produced by comparing the pre- and post-NOx SIP Call time periods, depicting; (1) change in ozone levels across the Eastern United States resulting from the NOx SIP Call, (2) change in ozone levels if the NOx SIP Call had not been implemented, and (3) change in ozone levels with no anthropogenic emissions present. These enriched maps of ozone concentrations will be aligned to census tract and county level resolutions and used to drive the population-based exposure models and the human health assessment discussed in the following sections.

Ozone Exposure Probability Estimates: This effort will generate isopleth maps depicting the probability of exposure to ozone (by age, gender and other cohort characteristics of relevance to exposure or health effects) before and after the implementation of the NOx SIP Call. These maps will identify the probability of exposure by age group and geographical area and will be provided to Columbia University and NYSDOH for use in the risk and health assessment portions of the effort. Exposure models will be used to assess the probability of ozone exposure before (2001-2002) and after (2004-2005) the implementation of the NOx SIP Call during the summer ozone season (June 1 - August 31) for the Northeastern U.S. and New York State (NYS). As discussed in the characterization section, other scenarios will be evaluated to (1) assess the impact of weather, (2) examine exposure if the NOx SIP Call was not issued, and (3) examine the impact of natural vs. anthropogenic emissions. These scenarios will help us understand what drives exposure to ozone (e.g., temperature, emissions), and how exposure changes under extreme emission conditions (upper and lower bounds).

Two exposure models will be used in this project to contrast and confirm results: The Air Pollutant Exposure (APEX) model (U.S. Environmental Protection Agency 2006a and 2006b), will be used at a 12km horizontal resolution for the Northeastern U.S. and NYS, and the Stochastic Human Exposure and Dose Simulation (SHEDS) model will be used for two smaller areas (one urban and one rural) within NYS. Both models will be run at a census tract and county level. The exposure models simulate the movement of people through time and space and their exposure to a given pollutant. The models stochastically generate simulated individuals using census-derived probability distributions for demographic characteristics. Any number of simulated individuals can be modeled, and collectively they approximate random sampling of people residing in a particular study area. Daily activity patterns for individuals in a study area, an input to the exposure models, are obtained from detailed diaries that are compiled in the Consolidated Human Activity Database (CHAD). The diaries are used to construct a sequence of activity events for simulated individuals consistent with their demographic characteristics, day type, and season of the year, as defined by ambient temperature regimes.

Risk Assessment: Risk assessment will be used for assessing health effects of ozone associated with alternative regulatory scenarios. Risk assessment takes advantage of measured and/or modeled ambient concentration data and published concentration-response function to estimate ozone-related health impacts. Concentration-response functions from available epidemiological studies will be used to estimate the change in hospital admissions and mortality corresponding to changes in ozone levels from before, during and after the NOx SIP Call implementation. In addition, we will estimate health effects for hypothetical no-control and full-control emission scenarios. Because epidemiological studies differ in their estimated concentration-response functions, we will calculate health impact estimates from multiple epidemiological studies. The concentration-response functions for a specific health endpoint can vary due to data availability, statistical methods, the communities' underlying population health, and other factors. Still, the published relationships between ozone and health can provide a useful gauge of the health impacts that may occur with changes in air quality. We will consider epidemiological studies based on U.S. cities (Kinney and Özkaynak 1991, Schwartz, 1994, 1995; Moolgavkar et al., 1997; Levy et al., 2001; Thurston and Ito, 2001; Stieb et al., 2002, 2003; Bell et al., 2004; Bell et al., 2005). The epidemiologic literature on ozone health effects will be used also to estimate the confounding effect of short-term weather influences on respiratory hospitalization rates. This information will be used during the subsequent health assessment.

Health Assessment: The health assessment will examine the methodology to track potential respiratory health impacts resulting from control actions. The specific objective is to characterize and track the magnitude of changes in hospital admissions for respiratory diseases in NYS during 1997-2005, and before and after the implementation of the NOx SIP Call. The design of this study includes a longitudinal and a cross-sectional component. The longitudinal component will compare the number or rate of respiratory hospital admissions pre- and post-implementation of the NOx SIP call, while controlling to the extent possible, temporal changes in important factors, such as temperature, population size/demographic composition, availability of hospitals/hospital beds, reporting and coding procedures, etc. This approach will minimize confounding factors due to socio-demographic characteristics by using the hospital admissions in the same geographic area pre-implementation as the control for the admissions post-implementation. The cross-sectional component will compare the rates between geographic regions in which ozone and NOx levels differ, while adjusting for many of the same influential factors mentioned above. This approach will control for seasonal and temporal trends in ozone and NOx levels resulting from other effects, such as other regulations implemented during the same time period.

Several existing data sources will be used: (1) the Statewide Planning and Research Cooperative System (SPARCS) is a legislatively mandated database, maintained by the NYS Department of Health, of hospital discharges from all hospitals in NYS (excluding psychiatric and federal hospitals); (2) data collected by the NYS Department of Environmental Conservation (NYSDEC) of ozone concentrations at 32 monitoring sites throughout NYS and NOx levels at eight urban monitoring sites or ozone concentration estimates based on the CMAQ model at 12 km horizontal resolution provided by the EPA; (3) the 1990 and 2000 U.S. Censuses, which provide data on population characteristics; and (4) Ozone Exposure Probability Estimates (from an exposure model) will be developed and provided by the EPA for 2001, 2002, 2004 and 2005, based on CMAQ simulated ozone concentrations as well as the fused modeled and observed values.

All residents of NYS will be included in the analysis. Health outcomes will include the number and rate of hospital admissions for respiratory diseases. Weekly, monthly, and yearly respiratory hospital admission counts and rates during the study period will be computed. The count and rates of hospital admissions for each of the selected ICD-9 codes and for combined disease categories will be calculated using the population from the 2000 U.S. Census data as the denominator. Different exposure lag periods (0,1,2,3,4 days prior to admission) will be examined. Exposure will be defined in several ways: (1) the pre- and post-implementation periods will be used as an exposure surrogate cut-off; (2) ozone and NOx concentrations from the NYSDEC monitoring stations will be plotted and examined by year and used to define exposure periods and regions; and (3) EPA will provide an isopleth map depicting the probability of exposure while controlling for activity pattern and respiratory rate for selected years, which will be used to link the health outcomes and ozone levels pre- and post-implementation of the NOx SIP call.

Information on various potential confounders is available through hospital admission data and the U.S. Census. These data include population density, hospital density, and population distribution by race, ethnicity, age, sex, median family income, and poverty level. In addition, factors that may affect exposure are meteorological conditions and day of the week. Because we are focusing on the ozone season only, seasonality is not expected to be a major concern. We will use the findings from the risk assessment to guide us to select several different statistical approaches for examining the ozone-disease associations. Depending on the adequacy of statistical power to detect a hypothesized association in health effects resulting from predicted reductions in ozone levels between 1997 and 2005, we will consider a variety of statistical methodologies ranging from descriptive analyses, such as displaying data or checking for trends, to longitudinal and cross-sectional analyses. As a first step in assessing longitudinal changes in health outcomes, we will use the Cumulative Sum (CuSum) method, a semi-quantitative approach, to investigate if there was a decrease in respiratory hospital admissions after implementation of the NOx SIP call. Relevant changes in demographics, weather conditions, hospital density/count, etc., will be explored to examine the influence of these confounding factors. This method may allow us to detect gradual decreases that may have occurred due to partial implementation of the ozone reduction measures before the full implementation date.

In the cross-sectional comparison, pre- and post-implementation (adjusted) hospital admission rates will be compared between geographic regions (urban vs. rural or New York City vs. upstate NY) and socioeconomic subgroups (such as age groups). In addition, the health outcomes from pre- and post-implementation will also be compared between the areas downwind of exposure sources and the areas upwind, and the days downwind and upwind. These analyses will be conducted stratified by year to capture changes that may be due to partial implementation of the ozone reduction measures or other normal yearly variations in the exposure.

III. Decision-making Context and Information Architecture (2 pages)

This proposal contributes to the over-arching Global Earth Observation System of Systems (GEOSS) by connecting air quality and health information in a common framework that gives researchers, decision-makers, and citizens seamless and straightforward access to environmental information. It is directly related to the near-term opportunity for air quality. Specifically, this proposal will result in a set of indicator maps that can be used on a temporal scale of days-to-seasons to assess ambient ozone concentrations and exposure risk probability estimates across age groups and geographical locations. These maps can be used to track the near- and long-term impact of regulations and the response signal in human health outcomes. In addition, these maps can be used to evaluate various “what if” scenarios to assess those actions that result in the most effective impacts on human health from emission changes, taking into account such factors as chemical interactions, weather, and the combination of anthropogenic and natural sources. This information is also useful in providing better health advisories to susceptible populations using the air quality forecasts.

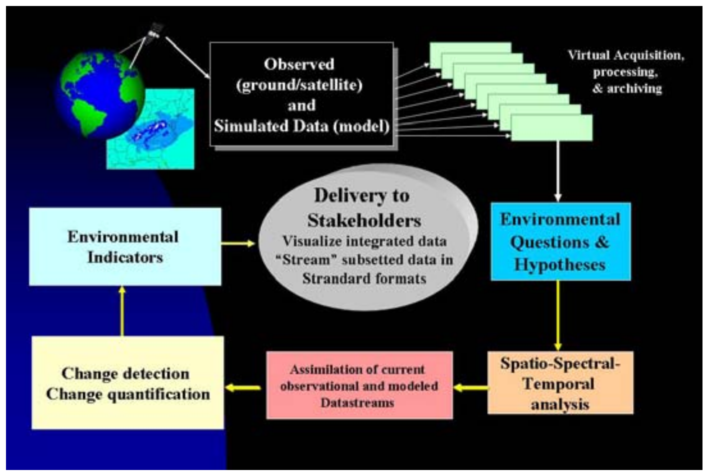


Figure 1: Remote Sensing Information Gateway Delivery System (modified from D.G. Goodin, Kansas State University, and G.M. Henebry, University of Nebraska presentation, 2006)

The Remote Sensing Information Gateway (RSIG) (Figure 1) will be used to generate and distribute ambient concentration and human exposure indicator maps on a daily-to-annual basis. This portion of the effort represents a substantial collaboration with OEI and leverages a significant architecture delivery and distribution system (U.S. Environmental Protection Agency, 2006c). In addition, a Geographical Information System (GIS) tool will be developed in collaboration with OEI to ease the combination of physics-based models with GIS approaches to assess relationships between environmental and human health information. This need for GIS tools has been documented through discussions with a multitude of users including OAQPS and state partners.

RSIG converts incoming proprietary file formats into standard formats selected by the user. RSIG allows the user to "stack" and view huge datasets and then select a subset of these data for analysis and/or export to a standard format--all within a matter of minutes instead of days to weeks as currently required. Interoperability and scalability are designed into the RSIG architecture as well. RSIG is compatible with other Agency systems (e.g., EnviroMapper, Window to My Environment, and Envirofacts) and is compliant with the Open Geospatial Consortium standards. Rather than focusing on the delivery of one product, the RSIG is designed to expand computational and data storage capacity as the need arises. More information on this delivery architecture is available in the GEOSS RSIG Program Plan (U.S. Environmental Protection Agency, 2006d).

The GIS Tool that will be developed as part of this project will automate and simplify what is currently a complex and laborious process to derive useful analytical and predictive results from raw data. With only small deviations, users repeat the same set of geoprocessing steps with every new input dataset. These procedures may include reprojection, resampling, extraction, format conversion, and overlay (Figure 2). Most of these geoprocessing steps are necessary to prepare a dataset for use with a custom-designed

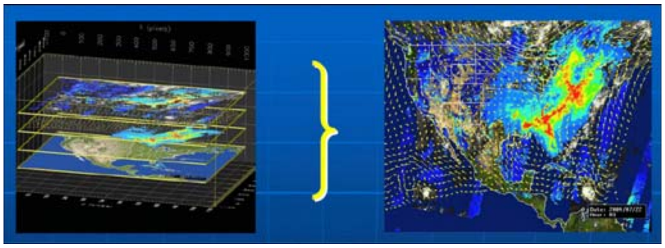


Figure 2: Remote Sensing Information Gateway Delivery System

FORTRAN-based modeling program, or to facilitate display of the model results on a map. Since air quality data are often generated daily (air quality forecasts) or several times a day (observations), the need for automation is clear, but researchers need freedom to customize their analysis within certain boundaries. For example, a user may wish to examine only a certain analyte, within a specific time period, a limited geographic area, and examine the effects on a small subset of the population. Rather than a one-size-fits all solution, we will develop a flexible tool that performs the desired processing quickly and easily.

Since most of the stakeholders utilize ESRI's ArcGIS software to perform geoprocessing and present results, ArcGIS's geoprocessing framework will be used to build the GIS tool. This platform confers additional advantages, including a familiar, easy-to-customize user interface with context-sensitive help for selecting the analysis inputs, and exposure to the Python scripting language, which can be used to integrate the FORTRAN modeling programs seamlessly into the process. Once developed, the tool can be easily packaged and made available for download through the RSIG portal. A coarse schematic showing the flow and delivery of information is shown below (Figure 3):

This portion of the effort will:

- Develop capability to generate accountability and exposure indicators on a daily-to-annual basis using "best" air quality forecasts (forecasts with current day meteorology assimilated and fused with ground-based air quality data).
- Generate GIS-based tool to package results.
- Distribute tool and integrated datasets via the RSIG.

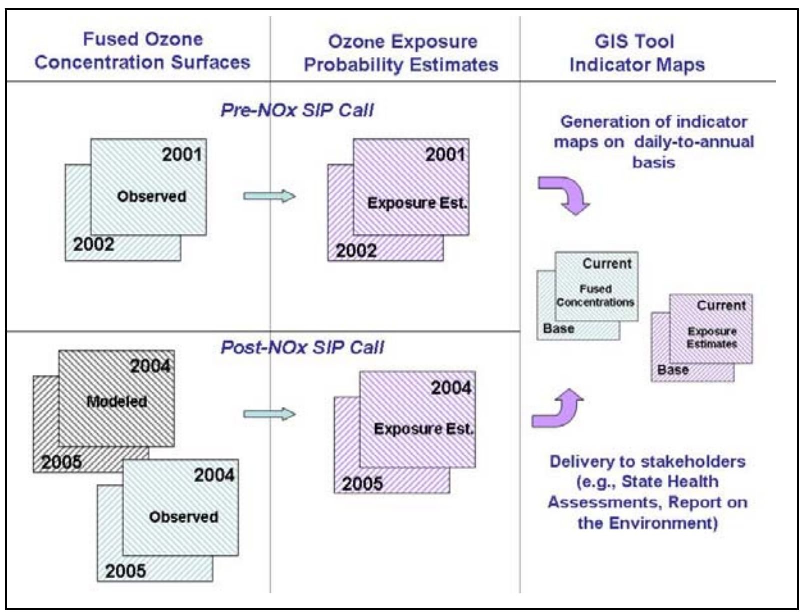


Figure 3: Flow of accountability data, and generation and delivery of indicators.

The methods developed through this pilot will be transferred to the states and also used to assess the impact of subsequent regulations, such as CAIR and CAMR.

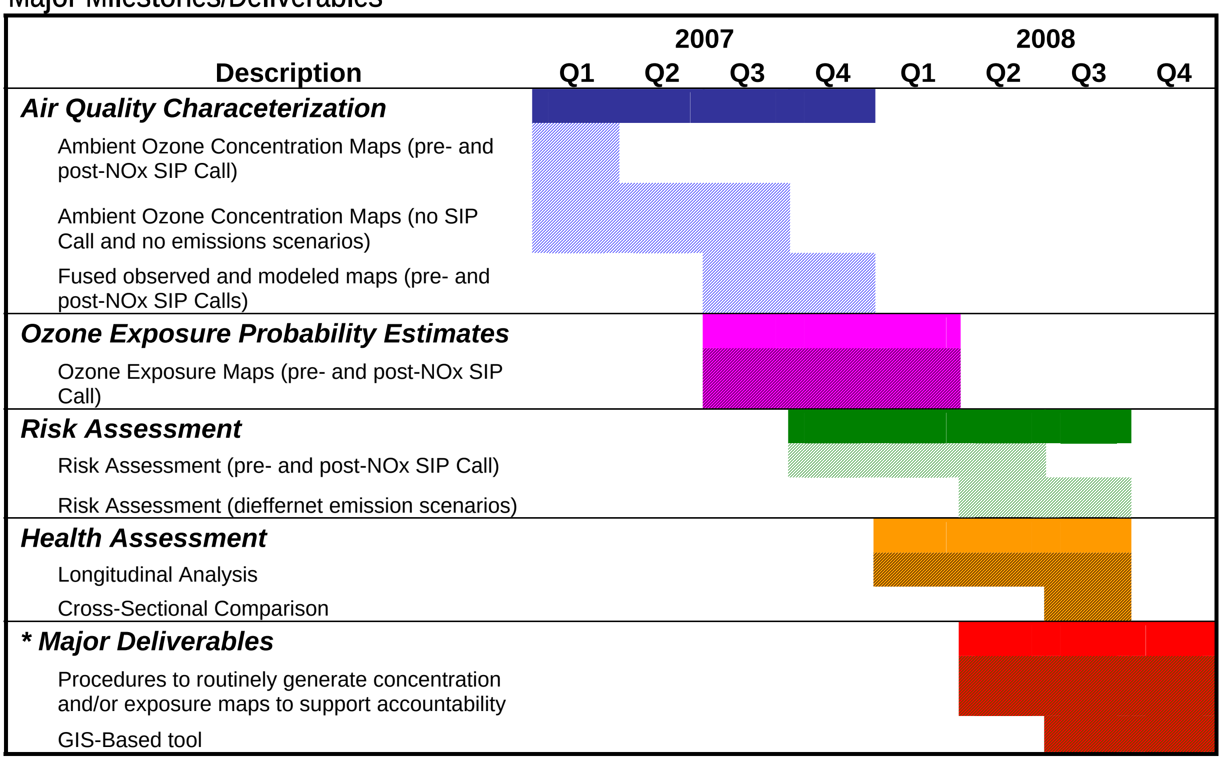
IV. Budget, Work Tasks and Leveraging (2 pages)

Critical Work Tasks: Critical work tasks are defined for each major task in Section III of this proposal. A summary of the major tasks and assigned leads, followed by the project schedule, is shown below.

Project Leads: Valerie Garcia, Deputy Director, ORD/NERL and Dr. Halûk Özkaynak, Exposure Senior Scientist, ORD

Major Task	Lead
Air Quality Characterization: Quantify the impact of the NOx SIP Call on ambient ozone concentrations and transport atmospheric transport of pollutants.	Valerie Garcia, Deputy Director, ORD/NERL
Ozone Exposure Probability Estimates: Quantify the probability of ozone exposure above exceedance levels to populations before and after the NOx SIP call was implemented.	John Langstaff, OAR/OAQPS Dr. Vlad Isakov, ORD/NERL
Risk Assessment: Conduct a risk assessment to examine the health impact of simulated emission scenarios and inform the health assessment.	Dr. Pat Kinney, Associate Professor Columbia University
Health Assessment: Characterize and tract magnitude of changes in hospital admissions in NYS.	Dr. Nancy Kim, Director, Division of Environmental Health Assessment, NYSDOH
Delivery Architecture/GIS Tool: Develop capability to generate accountability indicators on a daily-to-annual basis using "best" air quality forecasts. Generate GIS-based tool to package results. Distribute tool and integrated datasets via the Remote Sensing Information Gateway.	Tom Scheitlin, OEI/OTOP Deborah Burgin, OEI/OIAA

Major Milestones/Deliverables



Budget Justification: This effort directly leverages hundreds of thousands of dollars in ongoing research efforts. The characterization of air quality before and after the NOx SIP Call represents ongoing work within the ORD/EPA. Efforts are continuing with existing EPA resources to investigate the atmospheric transport patterns and various modeling scenarios (e.g., no anthropogenic emissions, no controls). APEX and SHEDS exposure models, developed with previous resources, are being applied to produce exposure estimates. The partnership with the NYSDOH leverages ongoing efforts under the Environmental Public Health Tracking (EPHT) program with CDC. The collaboration with OEI leverages resources used to develop the RSIG infrastructure. Likewise, research being conducted by Columbia University (Dr. Patrick Kinney) under the NOAA-funded project will be utilized in the proposed project.

Resources obtained through the AMI program will be used to: (1) fund the fusion of the observed and modeled ozone concentrations; (2) run air quality and exposure models; (3) obtain expert consultation on the exposure and risk assessments; (4) provide graduate student to NYSDOH, and (5) develop the GIS tool.

V. Quality Assurance, Information Quality Guidelines, and Communication Strategy (1 page)

The overarching goals of this effort are to combine existing and future air quality data at various temporal and spatial scales in a manner that allows the evaluation of trends and assessment of exposure risk. Because we will be analyzing datasets at varying temporal and spatial scales, quality assurance, including the establishment of information guidelines, for each data type and step throughout the analysis is critical. Thus, a Quality Assurance Project Plan (QAPP) has been developed to address quality control issues associated with this effort and is available for review (QAPP for Remote Sensing Information Gateway, Revised Draft, June 2006). This document addresses the criteria for Category IV research and is organized into three sections: Project Quality Objectives, Theories/Methods/Techniques, and Quality Assurance Procedures. Software components and system architecture will be developed using the Evolutionary Delivery method (Figure 4). This software development methodology is based on a process in which developers and their managers work closely with the end users through an iterative process of making small development advances, demonstrating them, getting customer feedback, and then adjusting the development work accordingly. The advantages to this method include quick start-up, flexibility in changing details, and visible signs of progress. The QAPP also incorporates quality assurance plans developed for each dataset (observed and modeled) and provides details on how quality will be ensured for each data type throughout the process.

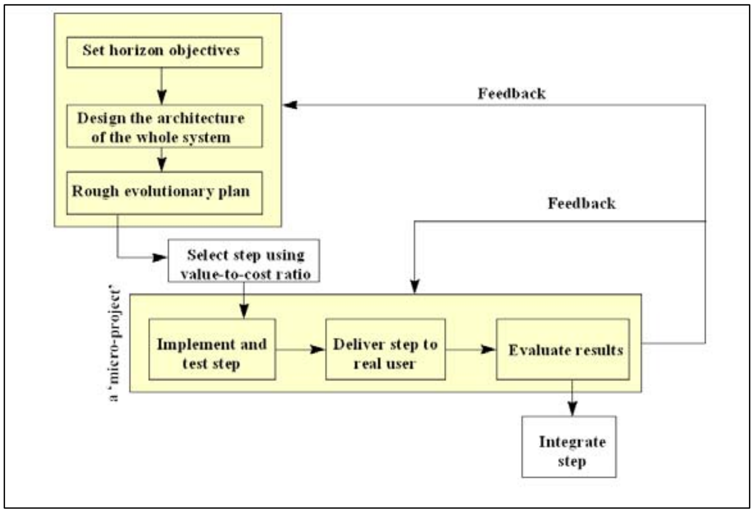


Figure 4: Evolutionary Delivery. Adapted from T. Gilb, and S. Finzi, Principles of Software Engineering Management. Addison-Wesley, Wokingham, 1988

Communication exists at several levels within this project, including inside the Agency, among interested Federal, State and academic partners, and with the stakeholders. The key is to involve all levels of participants throughout the process--particularly during the planning stage. For this reason, a team of diverse participants has been selected for this project, including EPA Program Offices (OAQPS, OEI and ORD), Agencies (NOAA, EPA), academia (Columbia University), and state decision-makers (New York State). These levels of participation are critical in designing accountability indicators that are meaningful to national policy developers and state decision-makers. The project will use a variety of communication methods, including regular meetings to discuss progress and periodic meetings with a larger group to provide updates and ensure the team is meeting expectations. Materials will be produced to inform all stakeholders of the project. The project will coordinate with other, related AMI projects and leverage resources and materials, where possible. Once proven successful, there will be a demonstration of the approach to a larger audience.

VI. Appendices

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